Gas jet Development at LBNL
Design, Production, & Test are advancing gas target performance

•Gas jets are used in wake field experiments for repeatable, high rep rate plasmas

•Accelerator performance depends critically on jet density, profile, and smoothness as well as on laser focus location in the jet. Jet optimization is likely to significantly improve performance.

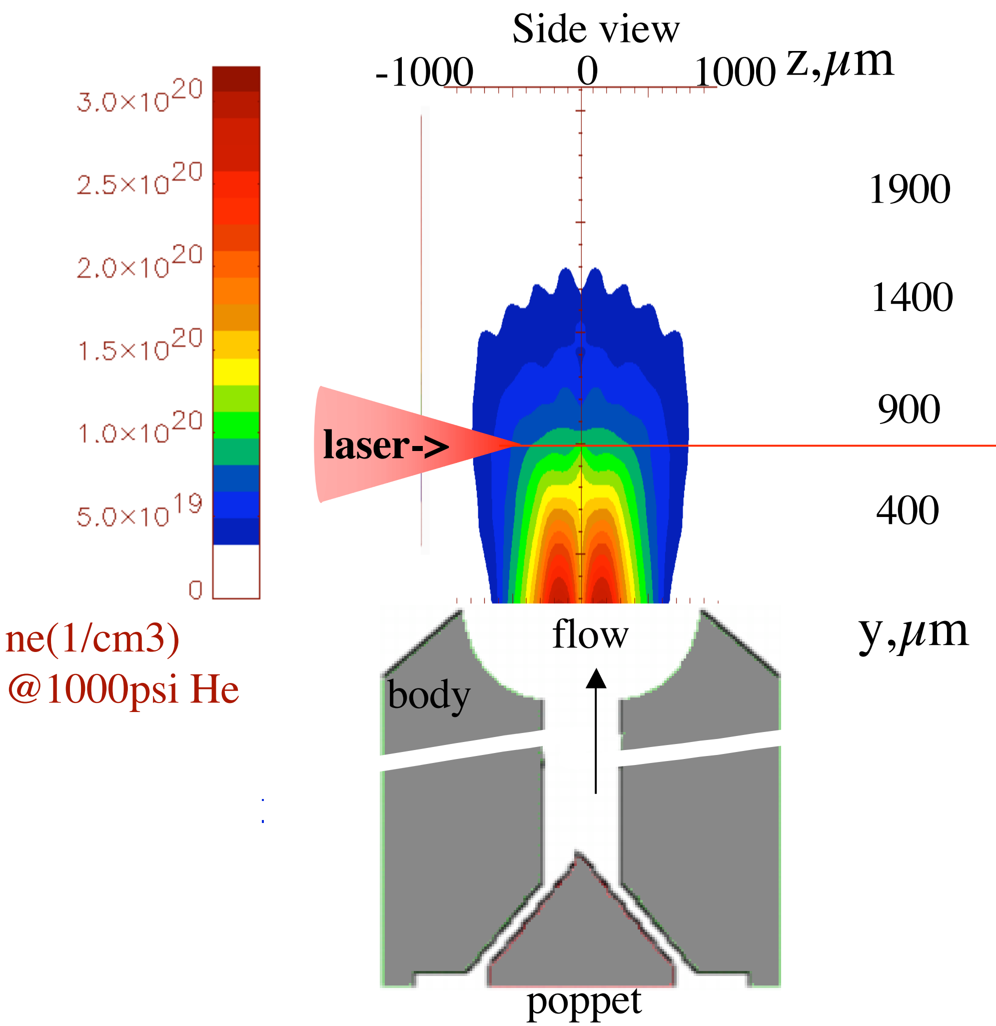
•Anticipated needs for optimal performance are challenging to achieve

•Jet development efforts at LBNL include:

-design and testing of new nozzle shapes (cylindrical and asymmetric)
fast quasi 1d tools and 3d flow simulations
-advanced machining to allow production of novel nozzle shapes
-development of new valve technologies (PZT, micro valves)
-Test stand for quick characterization of nozzles
-2w asymmetric imaging interferometer in the accelerator chamber

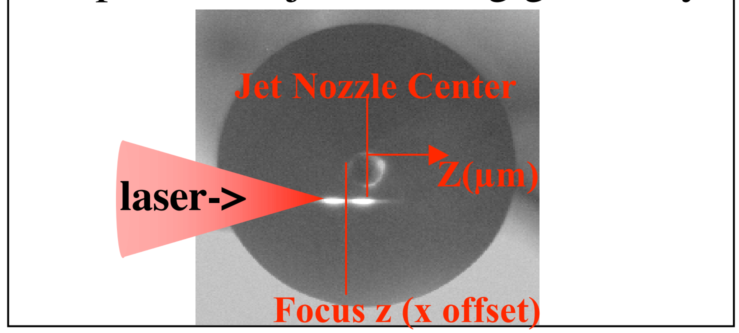
Accelerator performance is strongly affected by jet properties including back pressure, profile, z location

Jet Electron Density Profile

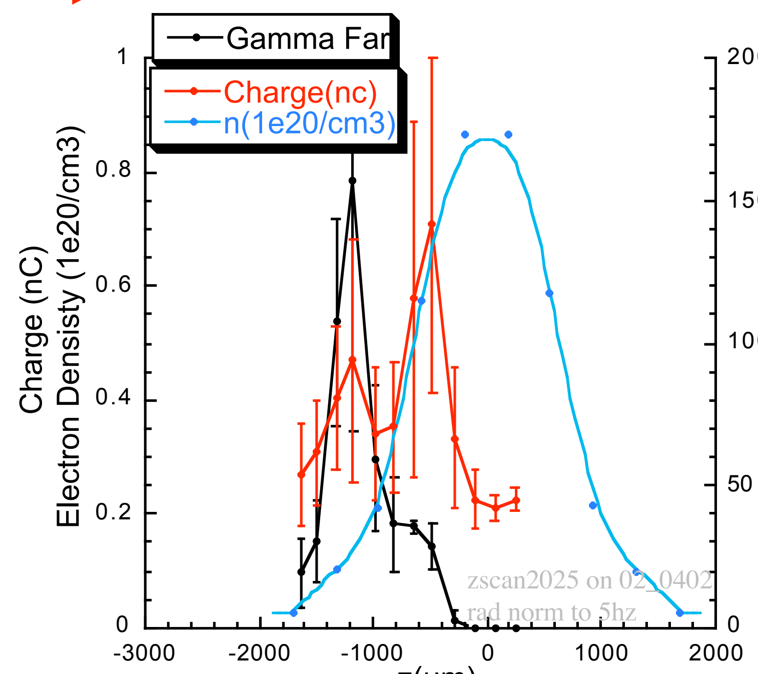


Jet cut Away

Top view of jet showing geometry

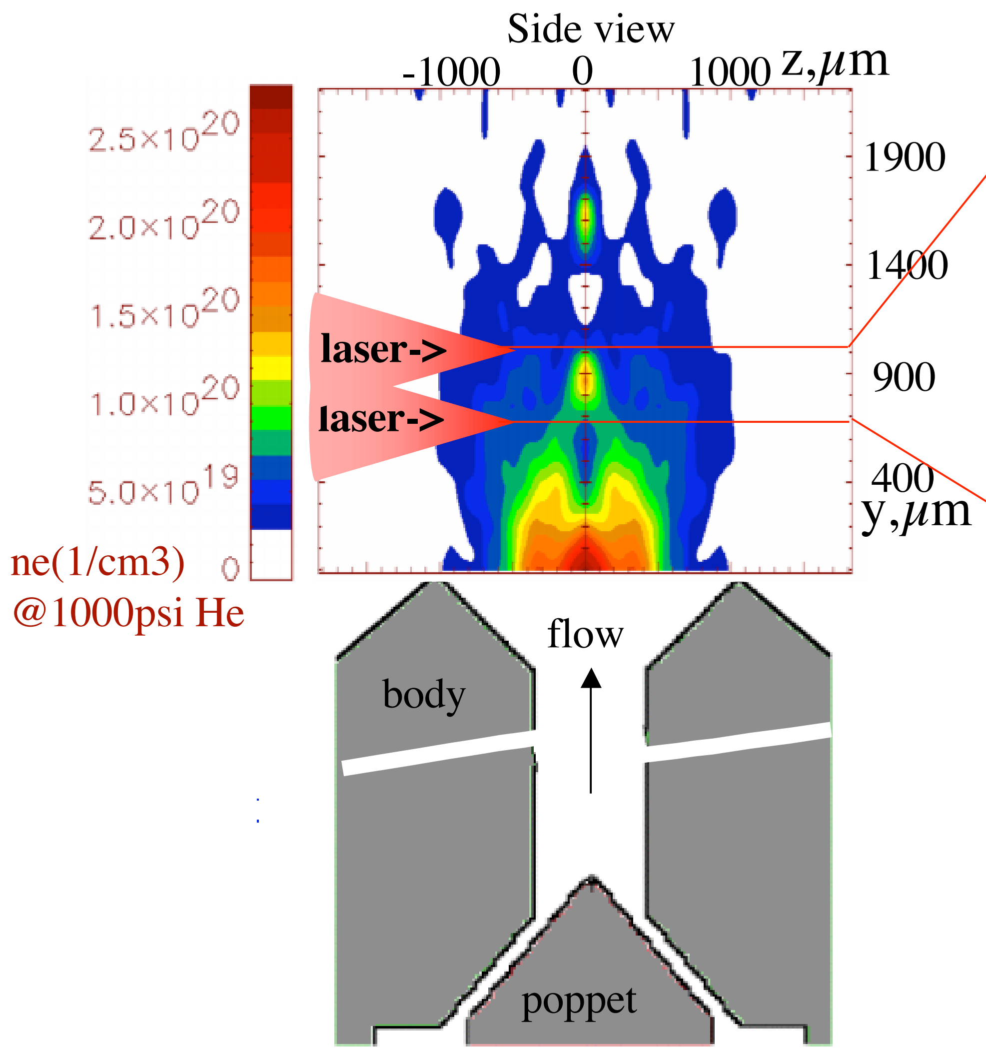


Yield vs. focus location, z @ y=710μm



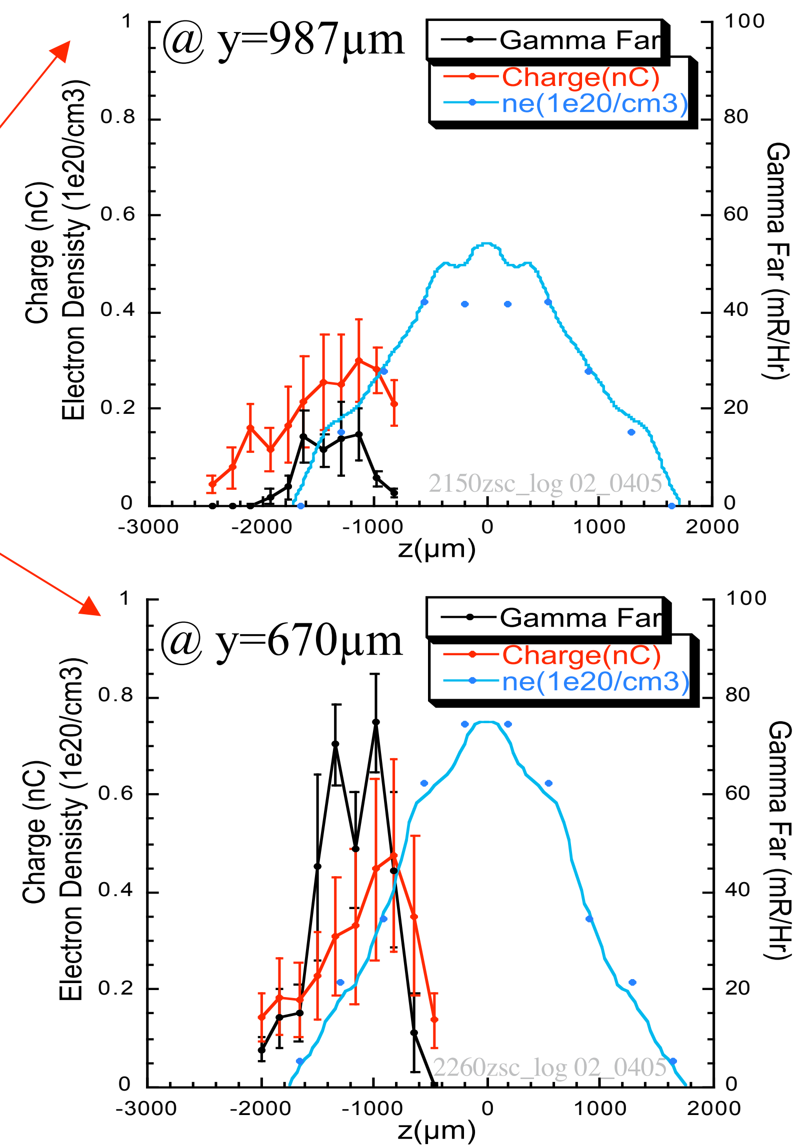
Jet optimization is under way to control and enhance accelerator output

Jet Electron Density Profile



Jet cut Away

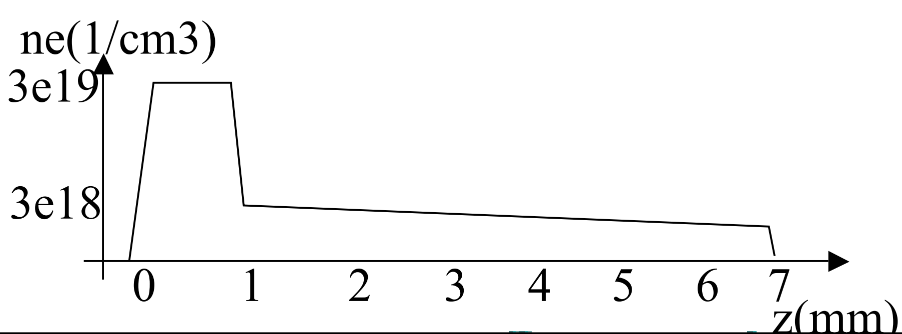
Yield vs. z



Wake field experiment gas jet needs & status

	Desired:	**Have**	**Solutions?**
Electron densities (He jet):	1e18 to 1e20/cm3	1e18 to 1e20/cm3	
Density gradients: (@1mm from nozzle)	~100μm	1mm	highly supersonic
Density fluctuations(@center)	< 5%	?	
2mm diameter round jets	X	X	
10-20mm long rectangular jets (<2mm wide to reduce pumping needs)	X		3d modeling
Fast gas pulses (100μs - 1ms) (practical pumping)	X		new valve technology (piezo, etc under study)
Shaped density profiles (control of injection and acceleration)	X		Multiple nozzles

Sketch of a gas profile of interest as a function of z
transverse profile insensitive at > 100μm scale

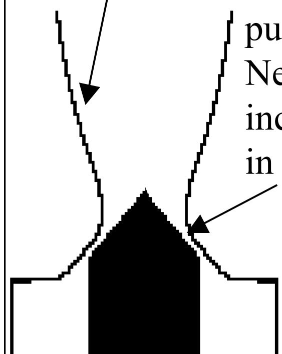


Sample of a few potentially interesting nozzle shapes

Cut away:

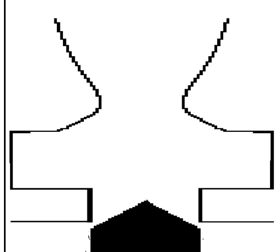
Bell or expanding profile for supersonic exit

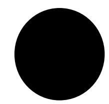
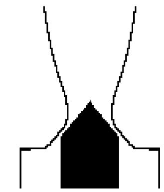
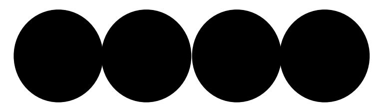
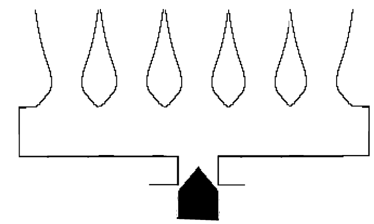
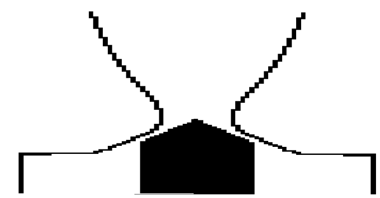
Valves do not pull back far. Need to include poppet in model.



gas reservoir

A chamber after the poppet may be needed



Type	Top View	Side View
Single round nozzle		
multiple round nozzles (fed from 1 valve or several small valves)		
rectangular nozzle (must fan out more in z than x)		
? Other ways		

1d wall following perfect flow code for fast nozzle modeling of cylindrical & rectangular sections

Use the equations of perfect gas flow in a variable area duct derived from assuming isentropic expansion of a perfect gas):

```
T/t0 = 1/((1 + ((gamma-1)/2)*M^2))
P/p0= 1/((1 + ((gamma-1)/2)*M^2)^(gamma/(gamma-1)))
rho/rho0=1/((1 + ((gamma-1)/2)*M^2)^(1/(gamma-1)))
A/Astar= (1/M)*( (2/(1+gamma)) * (1+((gamma-1)/2)*M^2) )^((gamma+1)/(2*(gamma-1)))
M=mach #
```

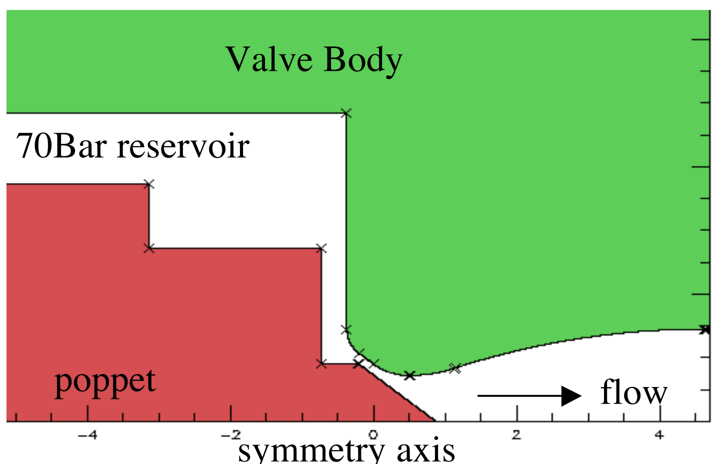
Calculate flow direction at each z location by looking for the minimum length line satisflying (assuming linear variation of flow angle over cross section- first approximation) :

```
thetan = theta2 + (b - r2) (theta1 - theta2) /(r1-r2)
              where b is the radius where equal area is inside and outside of r
              b = sqrt((r2^2 + r1^2)/2)
```

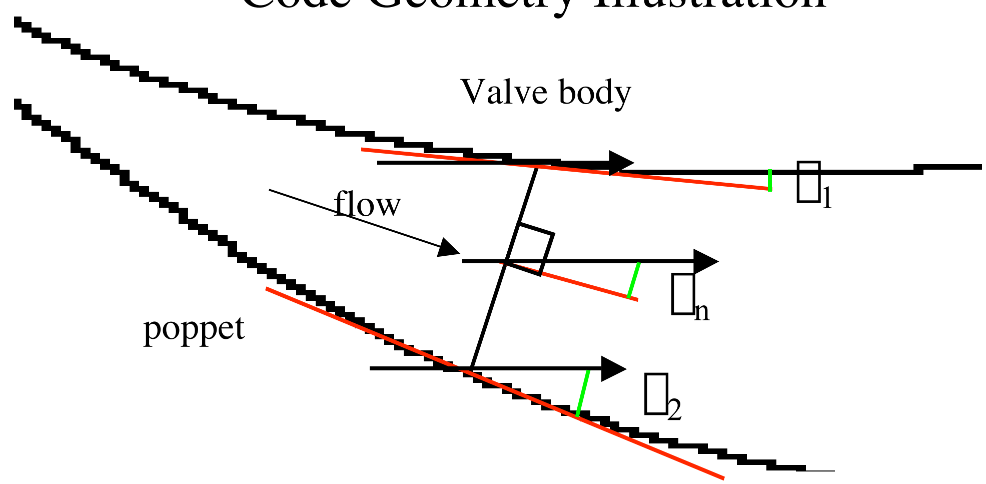
Allows fast optimization of nozzle shape for smooth mach # contour

Includes effects of flow direction changes due to poppet & throat shape.

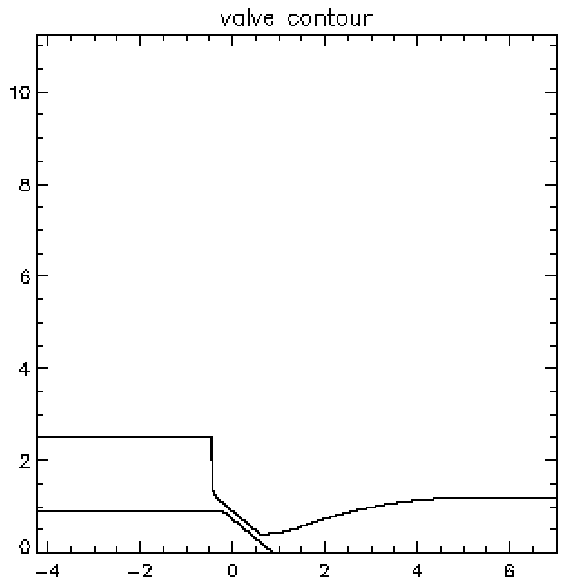
Nozzle Illustration (half)

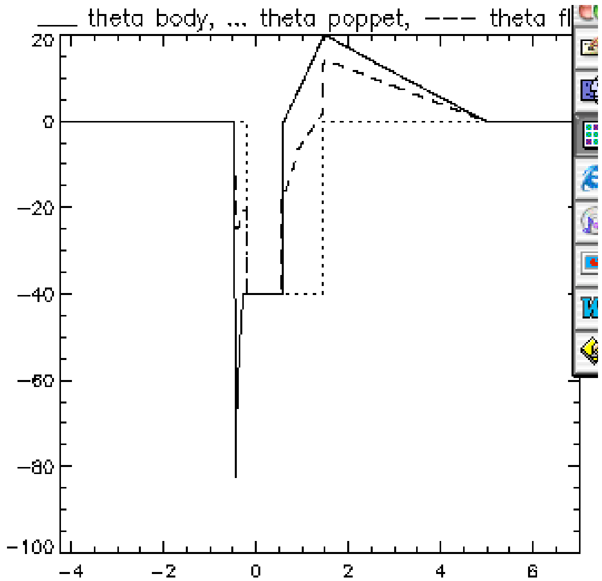


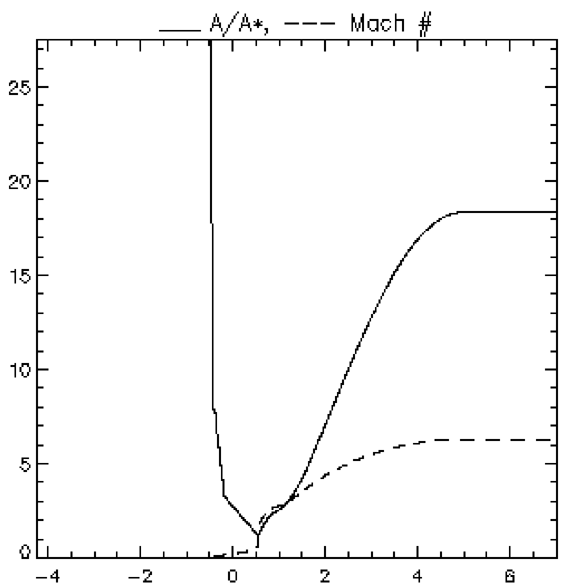
Code Geometry Illustration



Unoptimized nozzles have sharp transitions in Mach # creating shocks (04- GV Bell Nozzle)







;04- GV bell nozzle
Mon Aug 27 15:25:36 2001

Throat Data:
At=0.238461, Zt=0.552363

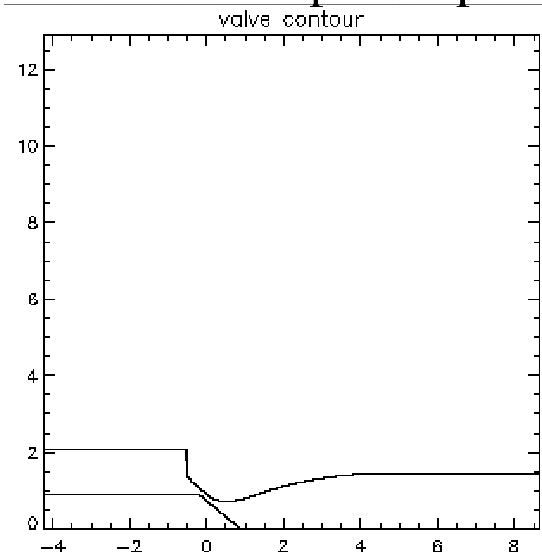
Opening & poppet data:
opening distance=0.196903, z(open)=0.349833
poppet area=1.15708, flow area at opening=0.416697
M at opening=0.350010, Max pressure=172.849

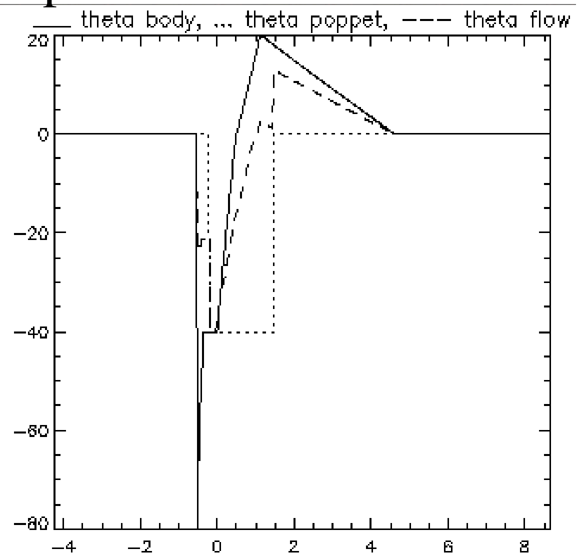
Outflow Data:
Ae/A*=18.3364 Ae=4.37253, Re=1.17977
Me=6.28001, RhomaxE=1.70257e+20, RhoE/rho0=0.0182408

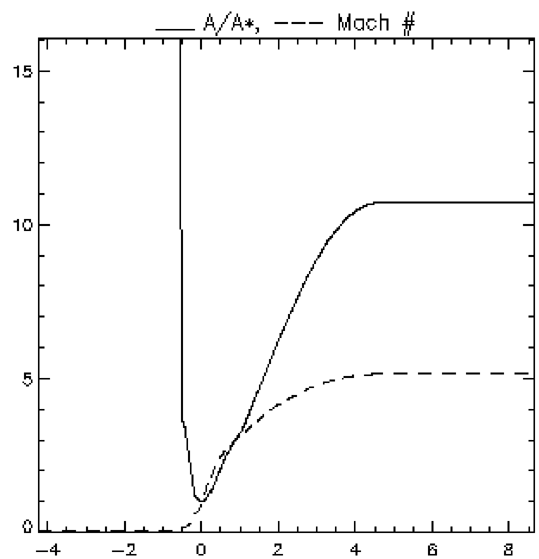
.7e20 rhoe @ 69bar

1d Code allows quick nozzle optimization, and output to 3d flow simulations (SciDAC collaboration)

Sample output - 1d optimized nozzle







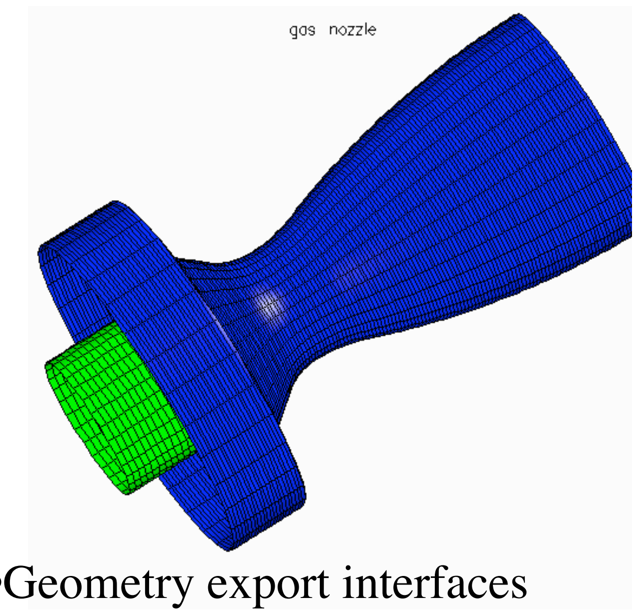
;06- GV bell nozzle redesign
Mon Aug 27 17:20:26 2001

Throat Data:
At=0.619303, Zt=-0.00384712

Opening & poppet data:
opening distance=0.193507, z(open)=-0.00384712
poppet area=2.56647, flow area at opening=0.619303
M at opening=1.00001, Max pressure=77.9281

Outflow Data:
Ae/A*=10.7017 Ae=6.62758, Re=1.45248
Me=5.14001, RhomaxE=1.33768e+20, RhoE/rho0=0.0317880

Geometry export example



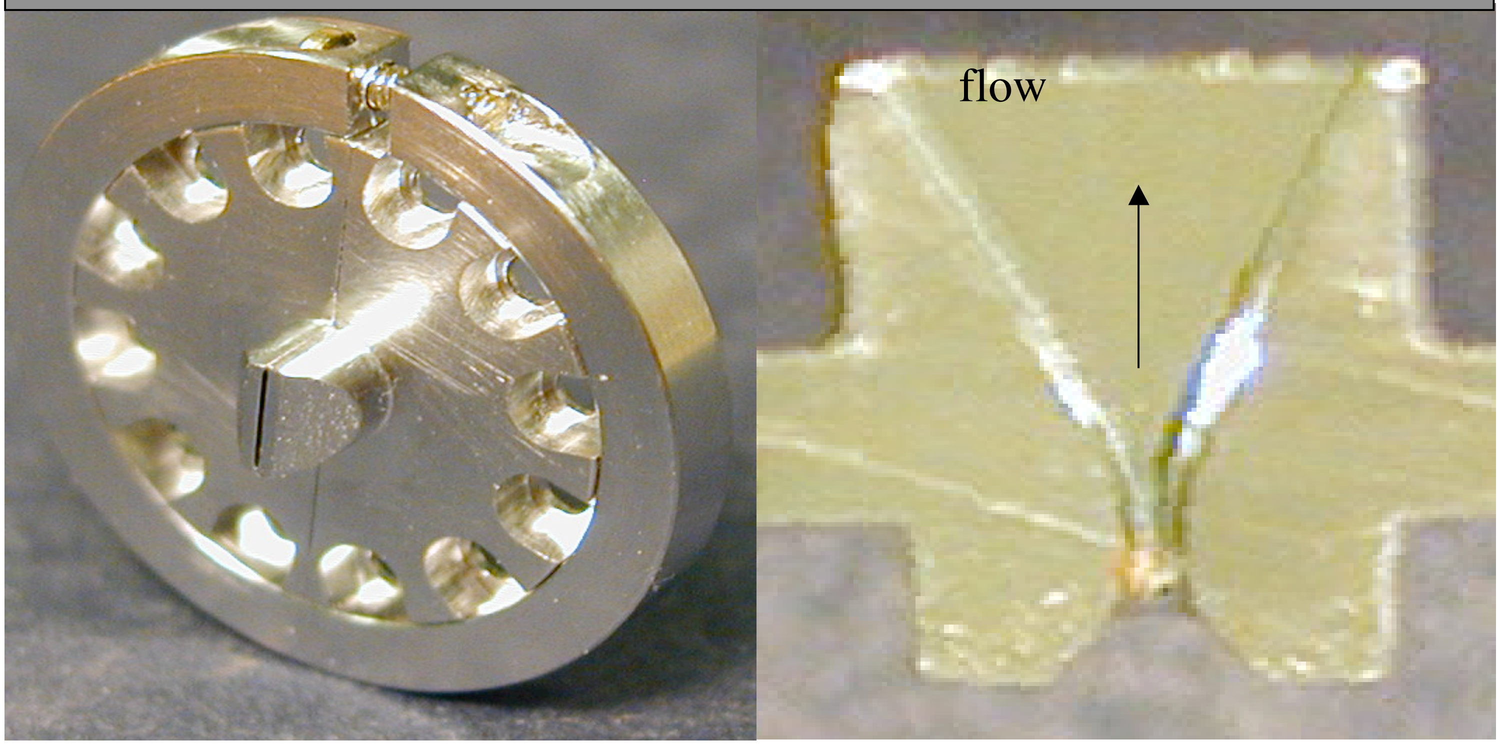
- •Geometry export interfaces to 3d flow codes and machining tools
- •SciDAC collaboration for 3d flow simulations is under way

Advanced nozzle shapes are possible through geometry export to CMC machining tools

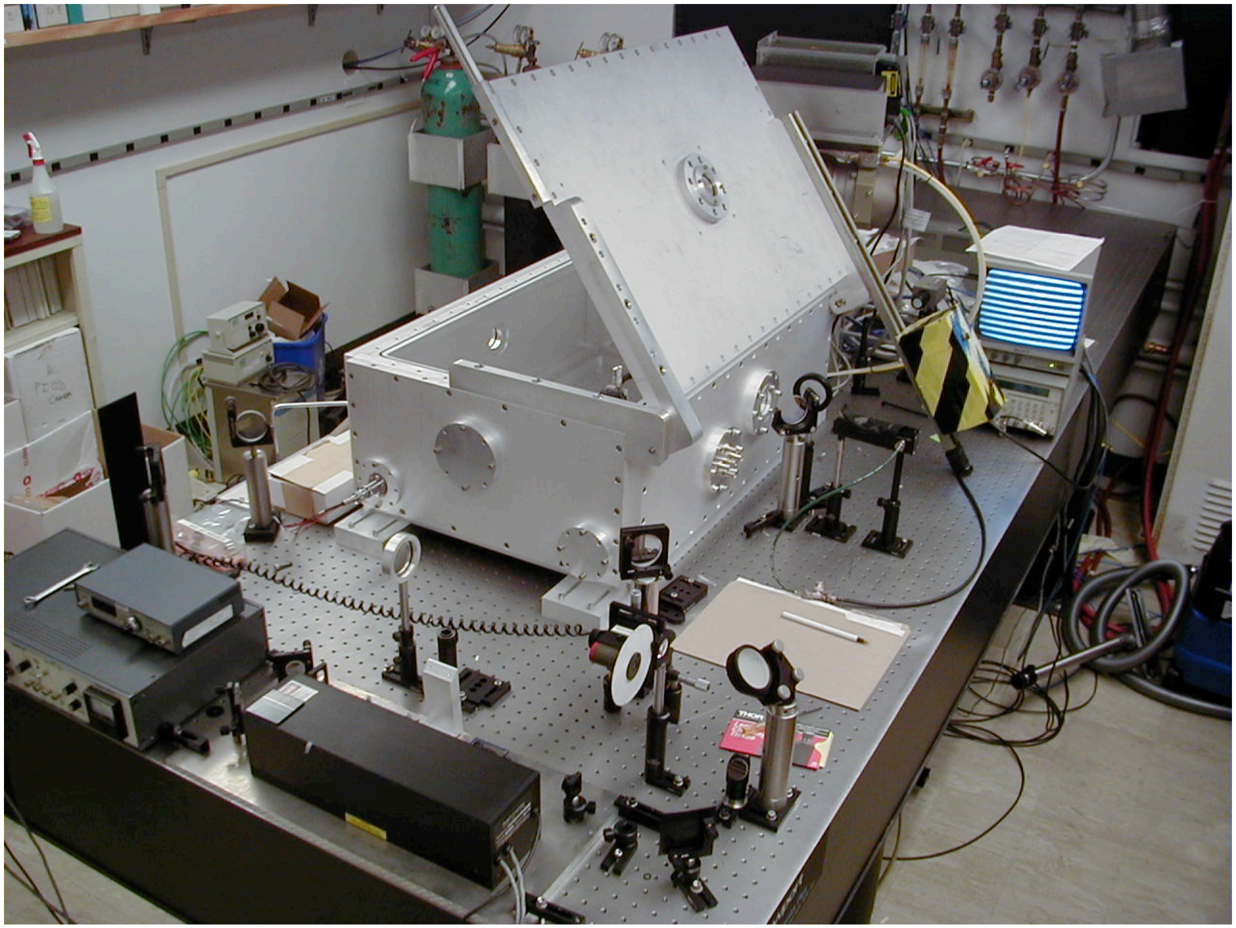
•Slit nozzles and other shapes not possible with traditional machining are being built using computer machine control with geometries exported from the design tools

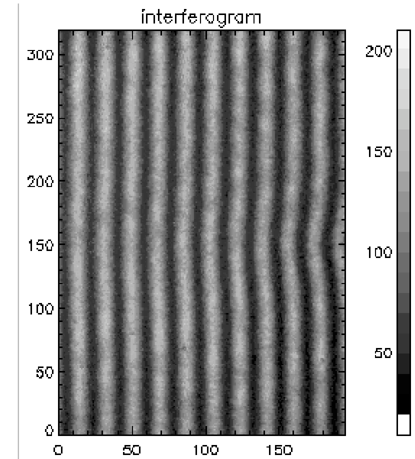
•First nozzle has been cut and testing is beginning

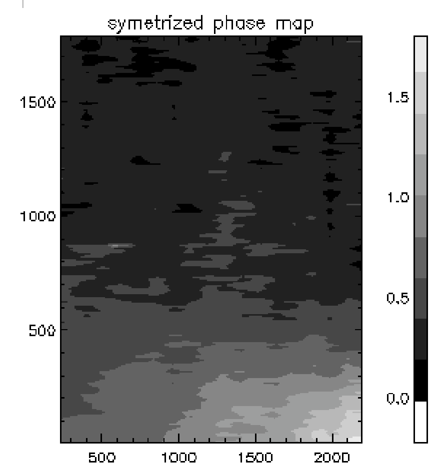
Slit Nozzle 200μm x 4mm



Test stand with HeNe neutral density interferometer allows fast characterization of nozzles



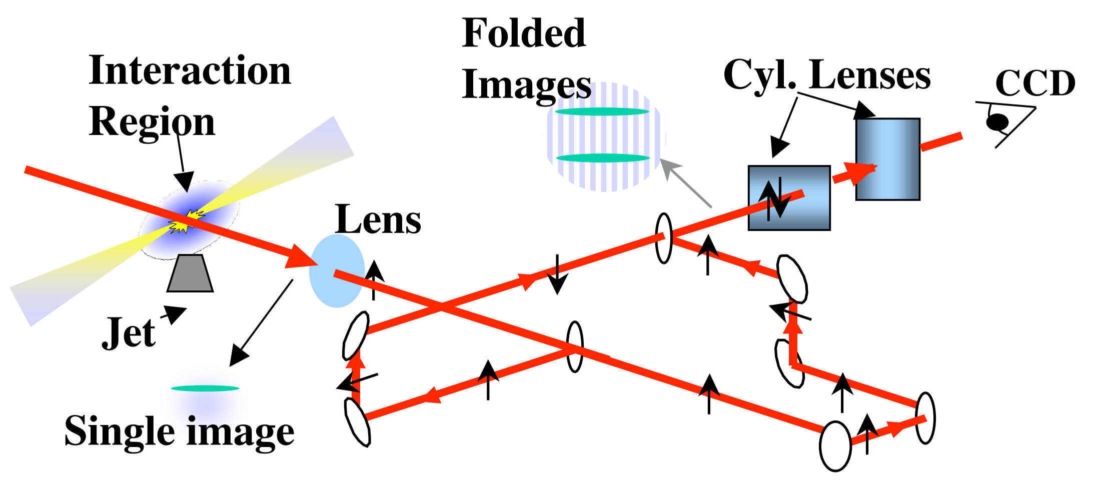




-Neutral density interferometer & fringe tracing recovers 2d phase map with ~0.05rad resolution
-Testing of cylindrical nozzles on solenoidal gas jets is under way
-Quick feedback allows rapid itteration of shapes

2ω interferometer with asymmetric imaging will measure plasma during system shots, separate sidescatter

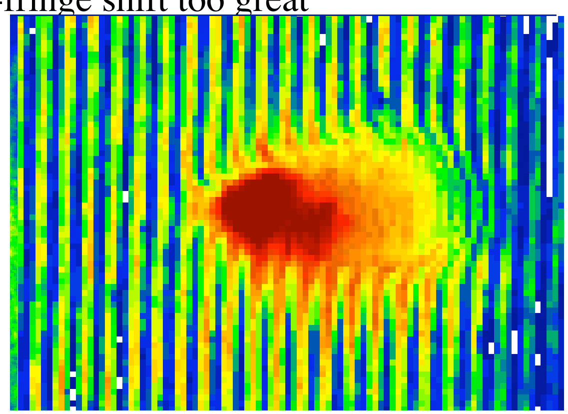
Interferometer Setup



- Interferometer upgrade has been fielded on accelerator and is taking first data.
- 1.4mm * 7mm asymmetric field of view allows imaging of long thin plasma channels
- Allows measurements of plasma at full system energy -> actual shot conditions

1ω Symmetric imaging :500 mJ

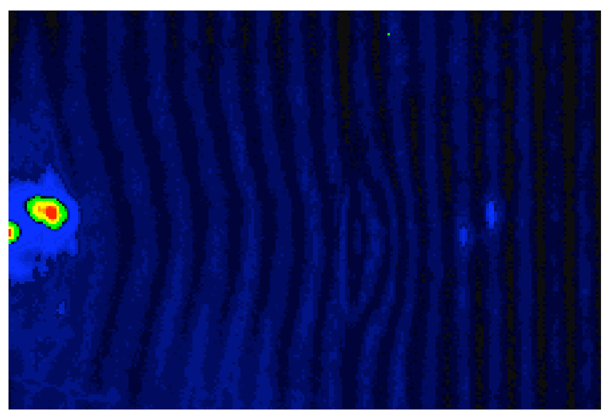
-sidescatter confuses interferogram-data un readable at high power
-insufficient resolution
-fringe shift too great



First images: Asymmetric 2ω interferometer

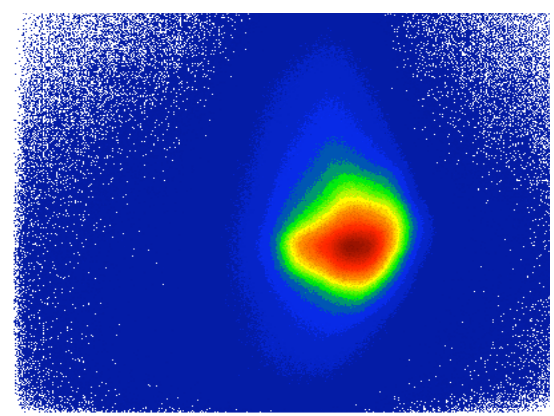
Partial interferogram: 500mJ

-sidescatter tolerable even at high power
-resolution, fringe shift good

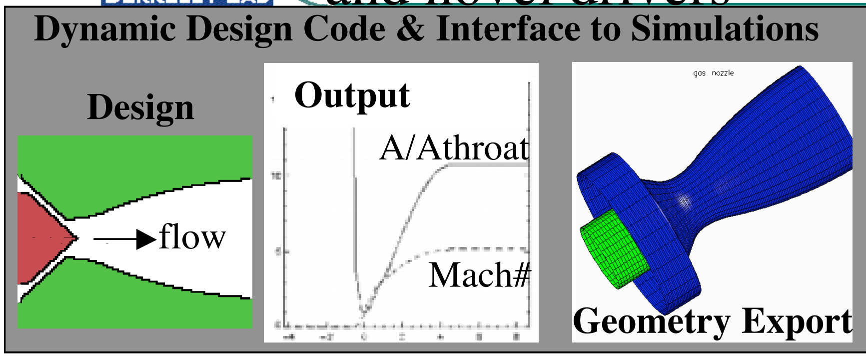


Side Scatter isolated:50mJ

-Separate analysis possible



Conclusion: New gas nozzles/valves are being developed using Test stand interferometer, design/simulation software, and novel drivers

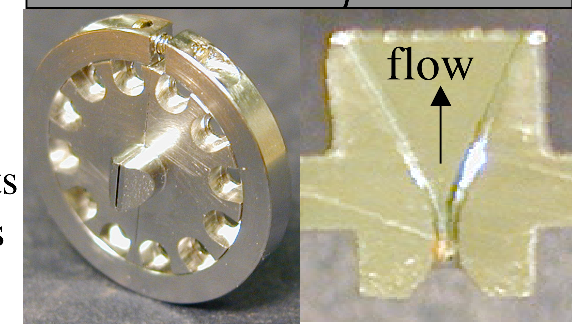


Design

-Quasi-1d gas dynamic design code allows fast nozzle design with feedback on mach profiles/etc.

-Geometry export interfaces to SciDAC flow simulations for 3d CFD nozzle simulations and to CMC machining codes

Slit Nozzle 200μm x 4mm



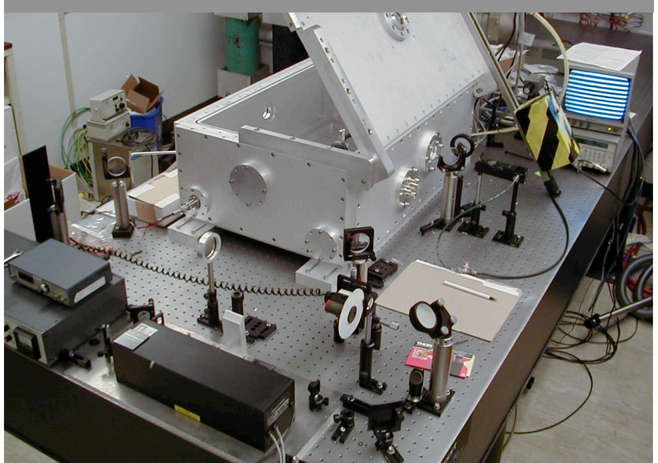
Production

-A PZT driven valve and driver have been designed and built to reduce opening time - starting testing

-Slit nozzle has been fabricated and is being tested to provide long, narrow jets

-Evaluating micro valve technologies for arrayed valves -> shaped gas profiles

Gas Jet Test Stand



Testing and Optimization

-HeNe interferometer with Chopper provides < 10μs time resolution

-Fringe tracing interferogram analysis software gives ~0.05 rad phase resolution and allows recovery of density profiles from neutral gas or plasma interferograms

-Testing and optimization of cylindrical nozzles on solenoidal gas jets is under way

-Testing of slit nozzles and new drivers is beginning